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# EVALUATION OF WATER SEPARATION AND FILTER/COALESCER IMPACT ON JP-8 BY NEXT-GENERATION +100 THERMAL STABILITY ADDITIVES


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**Interim Report**

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There were two goals for this program. The first goal was to evaluate and assess the impact of the primary next generation +100 candidate additives on the general performance of typical filter/coalescer systems in use by the United States Military. The secondary goal was to evaluate the applicability of this bench-scale filter/coalescer test to evaluating and assessing water separation characteristics of fuels.

Only additives P50, P47 and P41 exhibit either no or minimal negative impact on water separation and filter/coalescer performance and these additives are the most likely to be able to function in the field with minimal negative impact. However, there is cause for concern that additives P44 and P39 might potentially cause filter/coalescer issues in the field. It is recommended that these two additives be subjected to additional study before being approved for field implementation.

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# Acknowledgements

Special thanks to the Dennis Davis, University of Dayton Research Institute (UDRI) for setup of the ICE Rig and executing all the testing and taking all the photographs. Special thanks also to Andrew Sutkowski and Infineum UK for providing the filter test chamber and guidance in learning how to install and use it.

## List of Acronyms

| *Acronym* | *Definition* |
|---|---|
| AFRL | Air Force Research Laboratory |
| API/EP | American Petroleum Institute/Energy Institute |
| cm | centimeter |
| DLA | Defense Logistics Agency |
| DP | Differential Pressure |
| hr. | hour |
| ICE | Infineum Coalescence and Emulsion |
| mg/l | Milligrams per liter |
| mL | Milliliter |
| ppm | Parts Per Million |
| PSI | Pounds per Square Inch |
| RQTF | Fuels and Energy Branch of AFRL |
| UDRI | University of Dayton Research Institute |
| USAF | United States Air Force |

# 1.0 EXECUTIVE SUMMARY

Based on the results of photographic qualitative evidence and dissolved water measurements, Additive P50 performs the best with regard to water separation and filter/coalescer performance impact, being virtually the same as - and in one case, better than - the unadditized fuel. This additive would be the first choice for use if the choice was based solely on water separation and filter/coalescer performance characteristics as it would likely have the least impact on filter/coalescer performance in the field

Additives P47 and P41 perform acceptably with respect to water separation and filter/coalescer performance. Both of these additives initially exhibit no negative impact on filter/coalescer performance but after a short period of exposure to these additives, filter/coalescer performance degrades.

Additives P44, P39, and the additive soup exhibit substantial negative impact on both water separation and filter/coalescer performance with P39 ranking the worst as it almost immediately disables the filter/coalescer. P44 and the Soup fair only slightly better.

In conclusion, only additives P50, P47 and P41 exhibit either no or minimal negative impact on water separation and filter/coalescer performance and these additives are the most likely to be able to function in the field with minimal negative impact. However, there is cause for concern that additives P44 and P39 might potentially cause filter/coalescer issues in the field. It is recommended that these two additives be subjected to additional study before being approved for field implementation.

## 2.0 INTRODUCTION AND BACKGROUND

One of the main logistical issues facing aviation fuel users today is water contamination in jet fuel. In the worst of cases, water contamination – especially free water - can cause catastrophic failures in the propulsion systems of aircraft and ground vehicles, especially at colder temperatures and higher altitudes where free water contamination can freeze and prevent fuel from flowing freely in the fuel system.

It is virtually impossible to prevent water from getting into fuel storage systems. Just exposing fuel to the air is opportunity enough for water to get into fuel. Water can be present in fuel in one of three typical ways. First, water can dissolve in fuel. A typical water-saturated kerosene-type fuel contains between 40 and 80 ppm dissolved water at 21 °C (70 °F). Dissolved water at this level is not typically a problem for fuel systems because the water stays with the fuel, does not separate out and passes through the system relatively benignly. Water can also exist in fuel as a fuel-water emulsion. This emulsion exhibits a cloudy or turbid appearance. As the emulsion is not easily separated into its components, emulsified water typically passes through the fuel system without affect as long as it is in small quantities. But, if large enough quantities are present, it becomes hazardous to the system – especially in flight. Finally, water can exist in fuel as free or dispersed water. Free water exists as a separate phase – most notably as a pool of water in the low point of a tank or in a low area of a pipe. Free water can cause a variety of significant problems and must be removed from the fuel and fuel systems prior to use to ensure fuel systems remain relatively clean and therefore safe and operational. Free water is particularly dangerous for flights at high altitudes and long durations where the pooled water can freeze due to the low temperature at high altitudes. If this water freezes in the wrong place at the wrong time, fuel flow can be interrupted – with potentially catastrophic consequences.

Obviously, removal of any type of water from a fuel system is highly desirable. Typically, the water in its various forms is removed from fuel by use of a filter/coalescer operating in two main stages – a coalescer/separator element (stage 1) and a final fuel filtration element (Stage 2). Stage 1 coalescers are constructed to mechanically agglomerate and separate the water from the fuel using tiny hydrophilic fibers to adsorb the water molecules contained in the fuel. These fibers are contained within a soft cylindrical housing (commonly known as a ‘sock’). The fuel flows from either inside the cylinder to the outside, or vice-versa, depending on manufacturing. As the hydrophilic fibers become saturated with water, they release the water into relatively large water droplets, which sink to the bottom of the filter case due to their heavier density (see Figure 1, Right). In the final filtration stage (stage 2), particulates are removed from the fuel allowing clean and dry fuel to exit the coalescer/separator and into the fuel system.

The coalescer/separator cartridges used in the Stage 1 are cylindrical in design, and may have fluid flow travel inside out or outside in, depending on manufacturing.

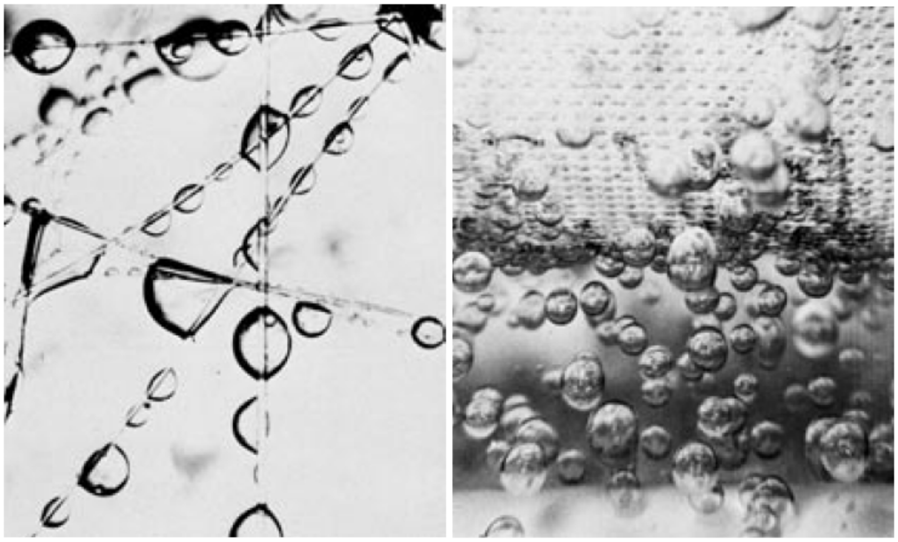

**Figure 1 - Photomicrograph of Coalescing Process Inside Fiberglass Media (Left) and Coalesced Water Drops Releasing From Knitted Sock At the Outside Surface of the Cartridge (Right)**[1]

Currently, the USAF uses two main types of filter coalescers. The first is a vessel originally designed for the DoD (American Petroleum Institute/Energy Institute, API/EI 1581 3rd Edition) specifications. It has a two stage filtration and the flow is inside-out on the coalescer/separator and inside-out on the filter. This design is still used in some of the mobile fleet and fixed facilities but they are being phased out as new equipment is being manufactured. The filter coalescers in these vessels have progressed and are qualified to the latest API/EI 1581 3rd or 5th Edition specifications. The second filter coalescer used by the USAF is also designed to the API/EI 1581 5th Edition specifications. A version of this filter is also used and has an 'M100' designation. These filters are specially designed to be used with fuels containing the current fuel thermal stability-improving additive Spec-Aid 8Q462. Filter change-out criteria are different depending on the location of the vessel. If the filter/coalescer system delivers fuel directly to an aircraft, the filters will be changed either when the adjusted differential pressure (DP) reaches 15 psi, or every 36 months or when the vessel performance is unsatisfactory or questionable. If the filter/coalescer system is located anywhere other than delivering directly to an aircraft, the filters will be changed either when the adjusted DP reaches 20 PSI, or every 36 months or when the vessels performance is unsatisfactory or questionable. The filter/coalescer criteria is the same regardless if the equipment is deployed or not.

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[1] Images Courtesy of Velcon Filters, Inc.

In a fixed facility, the filter/coalescer can be located at different locations. Inlet to the bulk storage systems (truck, pipeline, barge, railcar, etc.); transfer lines from bulk to operating systems and truck fill-stands. Depending on the severity of the fuel quality entering a base, there could be more filter/coalescers installed to accommodate changing filters during a receipt.

Aviation turbine fuel, on its own, is relatively resistant to water and the formation of emulsions. Regular draining of fuel systems is very effective at removing free water. However, the real key to maintaining water-free fuel systems is in the filter/coalescer systems. As long as these systems can perform as designed, water in fuel systems is a minimal issue. Almost every additive permitted for use in fuel, especially military aviation fuel governed by MIL-DTL-83133 (current revision), has the potential to adversely affect the performance of these filter/coalescer systems. This is why, when approving new or alternate additives for use in JP-8 and JP-5, water separation characteristics and the additive's impact on filter/coalescence systems is important. When the thermal stability additive for JP-8+100 was introduced in the mid-1990s, there was so much concern about the additive's detergent/dispersant components disarming filter/coalescers that restrictions were placed on blending fuel containing the +100 additive back into bulk fuel supplies. Such was the concern that, to this day, many urban myths exist about this additive's impact on filter/coalescer systems. As a result, a 10:1 (10 parts unadditized fuel to 1 part additized fuel) is mandated as the blend-back ratio for JP-8+100 fuels[2].

When a program was initiated to qualify alternate additives for +100 use, studying the impact of these potential new additives was of primary importance. However, since the only approved method of qualifying filters and coalescers for fuel required the use and consumption of tens of thousands of gallons of fuel, such testing was considered impractical for the program until it was absolutely certain that the field of candidate additives had been narrowed to only those with the highest likelihood to qualify. Yet, there was still a desire to have some sort of test that could provide some insight into how these new additives would impact water separation characteristics. The purpose of this report is to convey the findings of the evaluation of the candidate Next Generation +100 additives with regard to water separation impact on this smaller-scale test.

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[2] *Technical Manual, Fuels for USAF Aircraft, Tech Order 42B-1-1, paragraph 3.16 b(3)and (4).*

# 3.0 PROGRAM GOALS AND OBJECTIVES

In the 1990s, a thermal oxidative stability improver additive was developed by AFRL which increased the thermal stability of jet fuel by about 100°F. This additive, referred to as +100, is currently produced by GEBetz under the product name Spec-Aid 8Q462. In an attempt to broaden competition in this additive market, lower the additive price and improve availability, Defense Logistics Agency (DLA) initiated a program with AFRL to develop and approve alternates to the GEBetz additive. Over the course of a development and assessment program, four Next Generation +100 additives were defined as being potential alternates for the Spec-Aid 8Q462. Since there had always been concern about Spec-Aid 8Q462's impact on filter/coalescers but no test work had been specifically done to evaluate this, it was decided that these four candidate additives plus the original GEBetz additive would be evaluated for water separation properties and filter/coalescer impact.

Beginning in March 2007, the four +100 candidates and the original GEBetz additive were evaluated in the Infineum Coalescence & Emulsion (ICE) rig at AFRL. All additives were run through the standard test procedure and the data was collected and compared to the original +100 additive as well as 'neat' (unadditized) JP-8.

There were two goals for this program. First and foremost, to evaluate and assess the impact of the primary Next Generation +100 candidate additives on the general performance of typical filter/coalescer systems in use by the United States Military. The secondary goal was to evaluate the applicability of this bench-scale filter/coalescer test to evaluating and assessing water separation characteristics of fuels. It was not the intent of this program to replace API/EI testing protocols but to provide researchers with a bench-scale test that took minimal time and minimal fuel and could be used to 'rank' fuels with respect to their water separation characteristics.

# 4.0 EXPERIMENTAL

Over the years, many attempts had been made, with varying degrees of success, to develop a small scale test that could be used as a reliable screening tool. One such test method was developed by Infineum Co. (UK). It was developed based on earlier works in the field and was built specifically to evaluate the impact of Infineum's own additive candidate in the Next Generation +100 Additive development program. Since the Air Force Research Laboratory at Wright-Patterson AFB, OH was performing and/or managing the testing for this Next Generation +100 program, Infineum generously provided duplicate key components of their system to AFRL for use in the program so that all candidate additives could be equally ranked with respect to their impact on filter/coalescer systems using one evaluation system and set of criteria. The ICE rig was assembled in 2007 by University of Dayton Research Institute (UDRI) with assistance from Infineum. The filter test chamber was designed and fabricated by Infineum and provided to the Air Force for use in this program. The design of this system was based around using small pieces of actual filter/coalescer material to evaluate the impact of the additives on that material over a relatively short period of time, while being able to observe the fluid behavior through several clear viewing windows. Figure 2 shows a flow schematic of the system.

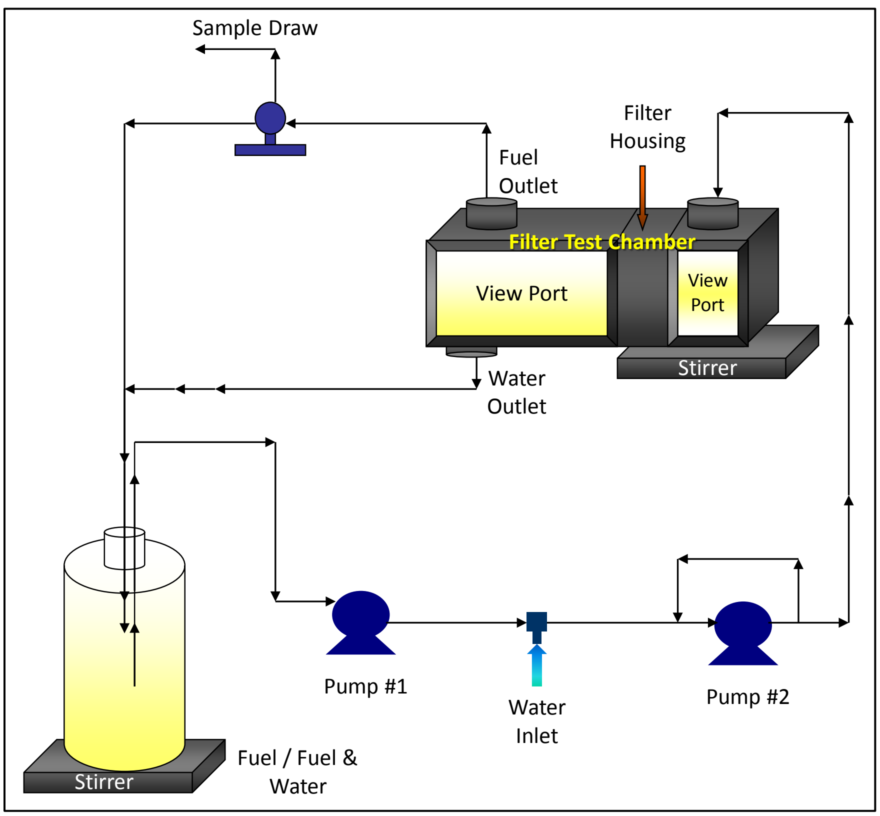



**Figure 2 - ICE Rig Flow Schematic**

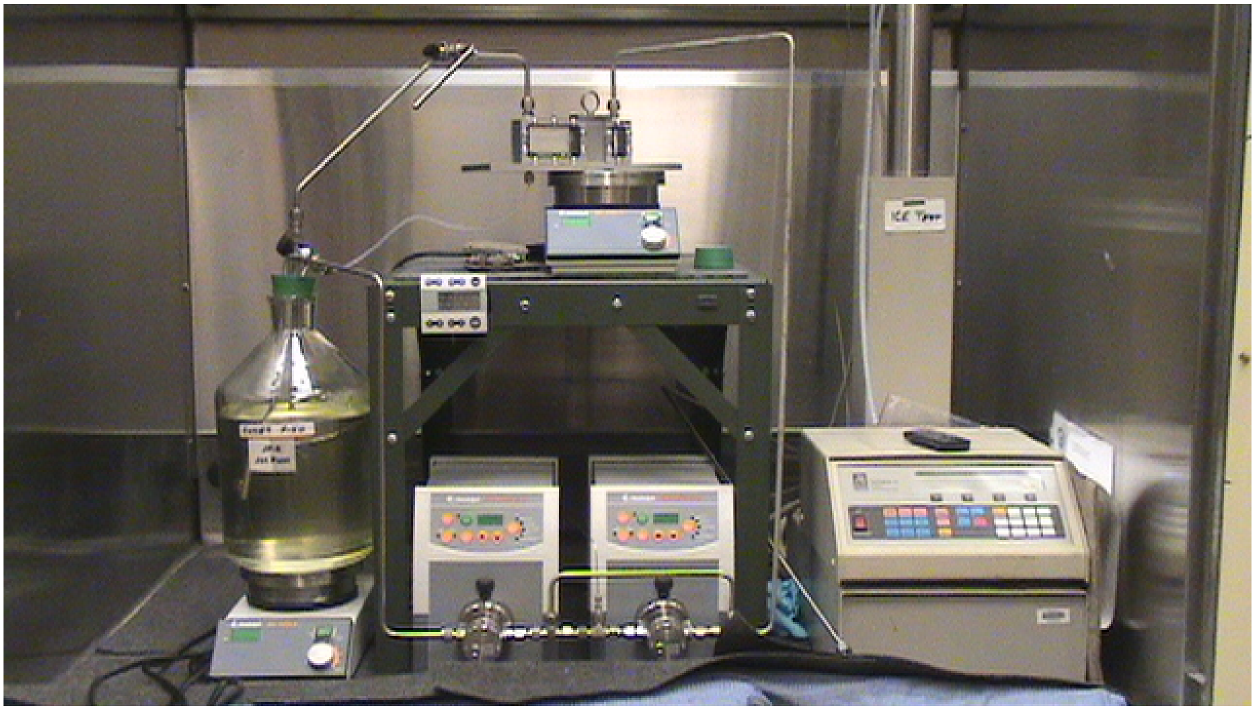


**Figure 3 - The ICE Rig**

Figure 3 is a photograph of the ICE rig setup. It consists of a 5-liter glass fuel storage container mounted on the left side of the rig supported by a magnetic stirrer, which is operated continuously during experimentation. Neat or additized fuel is pumped from this container through a gear pump, which begins to agitate the fuel, at a rate of 100 ml/min. The agitated fuel is then contaminated with reverse osmosis treated water at a rate of 4.5ml/hr. via a 1/16 stainless steel tube drip.  The 'wet' fuel is then pumped through a second gear head pump, set to operate at about 2,000 rpm, to homogenize the fuel and water mixture. After the homogenization pump, the fuel passes through a pressure transducer and into the filter test chamber.

The filter test chamber consists of a welded aluminum chamber divided into three chambers - two viewing ports and one filter case. Overall, the filter test chamber is about 5.5 inches in length, 2 inches tall and 1 inch wide. The fluid entry port is on the extreme right when facing the rig and is 1.5cm wide by 3.5 cm high, and contains a tiny magnetic stir bar to help agitate the fluid even more. From here the fluid flows through the two stages of filter/coalescer test specimen, which is cut to be slightly over one inch square. By cutting the filter pieces slightly larger than the one inch square hole, a good tight fit is ensured in the test apparatus so that all fuel passes THROUGH the filter and not AROUND it. The last port on the filter test chamber (extreme left) is 6.5 cm wide by 3.5 cm high. Both this port and the initial entry port are enclosed by safety plastic, sealed with Viton O-rings and several bolts (see Figure 4).

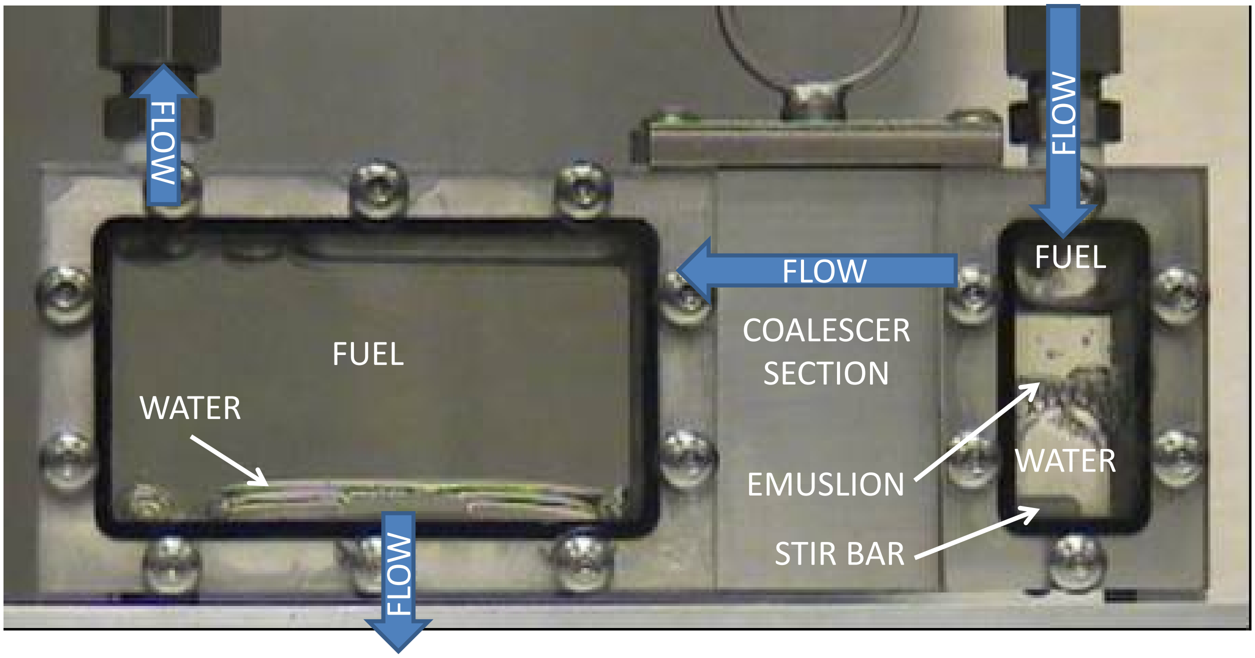



**Figure 4 - Filter Test Chamber**

The fuel/water emulsion created by the two pumps flows into the right chamber where a magnetic stirrer maintains the emulsion. This emulsion flows through the filter section where the filter separates the emulsion into a water phase and a fuel phase. Once the water and fuel have been separated by the filter section, both phases collect in the chamber on the left side where the two phases are allowed to acquiesce. The water is drained from the bottom of the cell through a control hand valve and into the original fuel supply reservoir. A separate needle valve in that line allows for fuel samples to be drawn and tested prior to re-contamination in the original fuel jug. Water is never removed from the system during the test. Fuel samples taken from the valve are analyzed by Karl Fischer[3] to measure dissolved water contamination levels. The fuel is pumped off the filter test chamber top and also flows into the original fuel supply reservoir. A magnetic stirrer maintains some limited liquid turbulence to minimize any natural separation of water from the fuel. This test demonstrates how well the filter/coalescer test section separated water from the fuel.

A normal test is conducted over a period of 72 hours, with photographic documentation at the start of the test and then at 1, 5, 24, 48, and 72 hours into the test. After the experiment, any fuel and water remaining in the test section are drained back into the original jug and allowed to settle for five additional hours. This aspect of the experiment demonstrates the behavior of the fuel additives that may

[3] *ASTM 6304 Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration*

have been mixed with the fuel sample prior to the start of the experiment. Since the filter/coalescers in field service typically see several thousands of gallons of fuel, the continuous flow of emulsified fuel/water passing through the test filter repeatedly is representative of the USAF's larger filter/coalescer systems.

For these tests, a section of a typical API/IP 5$^{th}$ Edition filter (non-M100) was used to provide the filter/coalescer pad used in the filter/coalescer test chamber.

# 5.0 RESULTS AND DATA-SPECIFIC DISCUSSIONS

## 5.1 Water Separation Performance by Dissolved Water Measurements

A well characterized baseline JP-8 (POSF-4751) fuel was used for all ICE testing involving the additives. Each Next Generation +100 candidate additive was added to the fuel for evaluation at a dosage rate of 256 mg/l. In addition to individual additives, a 'soup' of all the additives was also evaluated. This soup consisted of all five candidate additives, where each additive made up 20% of the soup. The additive soup was then added to the fuel at 256 mg/l for the testing. Table 1 shows a summary of data for all the ICE runs grouped by additive. Note that the run numbers are not sequential and there are gaps because other fuels and additives were being tested in the ICE apparatus as a part of a broader-scope program.

**Table 1- Summary of Dissolved Water Measurements, All Additives**

| Test | Additive | Fuel | Status | Fuel POSF # | Comments | AVG | MAX |
|---|---|---|---|---|---|---|---|
| 13 | None | JP-8 | Yes | 4751 | | 97 | 100 |
| 31 | None | JP-8 | Yes | 4751 | 3rd run | 98 | 128 |
| | | | | | | | |
| P39 | | | | | | | |
| 7 | P-39 | JP-8 | Yes | 4751 | Cloudy very early in reservior | 3765 | 5643 |
| 11 | P-39 | JP-8 | Yes | 4751 | Reservior cloudy first day & emulsion in lg chamber | 6647 | 8838 |
| | | | | | | | |
| P-41 | | | | | | | |
| 4 | P-41 | JP-8 | Yes | 4751 | POSF additive number 4164 | 473 | 722 |
| 16 | P-41 | JP-8 | Yes | 4751 | 4 day test | 137 | 195 |
| 18 | P-41 | JP-8 | Yes | 4751 | cloudy in cells | 235 | 290 |
| | | | | | | | |
| P44 | | | | | | | |
| 8 | P-44 | JP-8 | Yes | 4751 | Cloudy very early in reservior | 2114 | 3402 |
| 10 | P-44 | JP-8 | Yes | 4751 | Reservior cloudy first day, emulsion in lg chamber | 1250 | 1842 |
| | | | | | | | |
| P47 | | | | | | | |
| 6 | P-47 | JP-8 | Yes | 4751 | | 216 | 255 |
| 19 | P-47 | JP-8 | Yes | 4751 | | 165 | 215 |
| 30 | P-47 | JP-8 | Yes | 4751 | 3rd run | 223 | 284 |
| | | | | | | | |
| P50 | | | | | | | |
| 9 | P-50 | JP-8 | Yes | 4751 | | 80 | 82 |
| 12 | P-50 | JP-8 | Yes | 4751 | | 60 | 70 |
| 37 | P-50 | JP-8 | Yes | 4751 | | 74 | 83 |
| 38 | P-50 | JP-8 | Yes | 4751 | 2X | 88 | 110 |
| 39 | P-50 | JP-8 | Yes | 4751 | 4X | 98 | 128 |
| | | | | | | | |
| Soup | | | | | | | |
| 14 | Soup * | JP-8 | Yes | 4751 | 5 hours cloudy, 2nd day emulsion in both cells | 969 | 1687 |
| 20 | Soup * | JP-8 | Yes | 4751 | Cloudy on 2nd day, emulsion in small cell, small | 408 | 557 |

Figure 5 is a bar-chart plot of the Table 1 data. The **BLUE** bars represent Average Dissolved Water by Karl Fischer. These readings were taken at the start of the test and then at 1, 5, 24, 48, and 72 hours into the test. The Average Dissolved water represents a normal average of these values but did not include the pre-test dissolved water measurement. The **RED** bars represent the Maximum Dissolved Water measured at any time during the test.

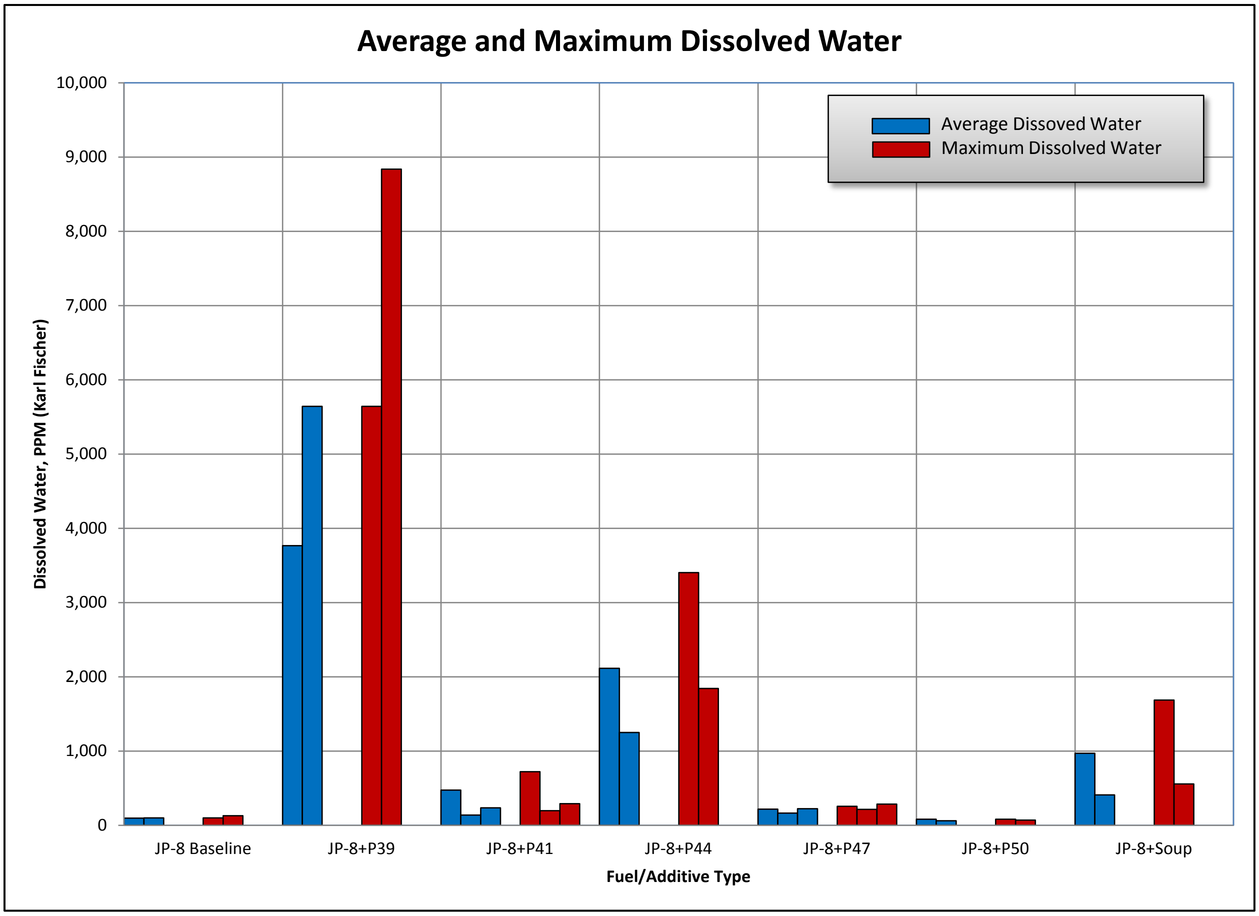



**Figure 5 – Summary of Dissolved Water Content for Fuels and Additives**

From the data in Table 1 and Figure 5, the baseline JP-8 showed a significant resistance to dissolved water. Additives P50, P47 and P41 showed significant resistance to dissolved water with P50 ranking as the most resistant and P41 ranking as the least resistant but not significantly worse than the baseline JP-8. Additives P39 and P44 were far worse than the other additives in rejecting dissolved water. The soup ranked slightly worse than the P41 additive, probably due to the impact of the P39 and P44 additives. Figure 6 shows the relative ranking of these candidate additives with respect to water separation.

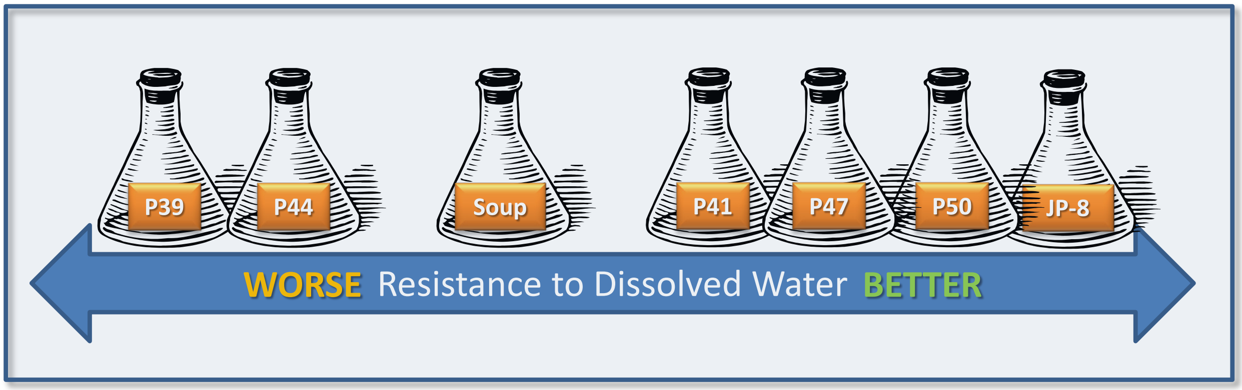



**Figure 6 – Ranking of Additives For Water Separation Performance**

## 5.2 Fuel Reservoir Images – APPENDIX

Figures A-1 through A-7 show the appearance of the fuel reservoirs during testing. In each Figure, the left-most image shows the condition of the reservoir at the start of the test. Progressing to the right, each image shows the condition of the reservoir as the test progressed. Finally, the right-most image shows the condition of the fuel reservoir 5 hours after the completion of the 72-hour test. This condition shows the degree to which water separates from the fuel in a acquiescent condition.

Figure 7 shows a table of subjective assessments of the clarity of the fuel/water in the fuel reservoir along with a 'key' relating the numeric clarity ranking to the physical appearance of the reservoir. The author has made an attempt at applying these relative numeric rankings of the clarity in order to attempt to rank the additives in order of effectiveness. *The reader is cautioned that these rankings are very subjective and open to some interpretation. Nonetheless, this ranking seemed to be an appropriate way to cross-compare the test results.*

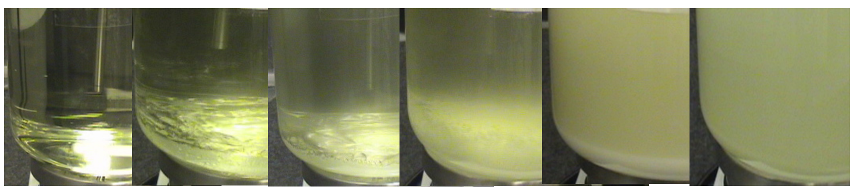
### *5.2.1 Baseline JP-8*

The Baseline JP-8 tests were Runs 13 and 31. In Run 13, some slight turbidity is noticeable at 5 hours into the test and this appearance remains relatively unchanged through the test. 5 hours after the test, the appearance remains unchanged. A significant amount of free water pooled in the fuel reservoir indicates good water/fuel separation.

In Run 31, again some slight turbidity is noticeable in the fuel starting at 5 hours. At 72 hours, this turbidity is slightly increased. 5 hours after the test, this turbidity remains. A significant amount of free water pooled in the fuel reservoir indicates good water/fuel separation.

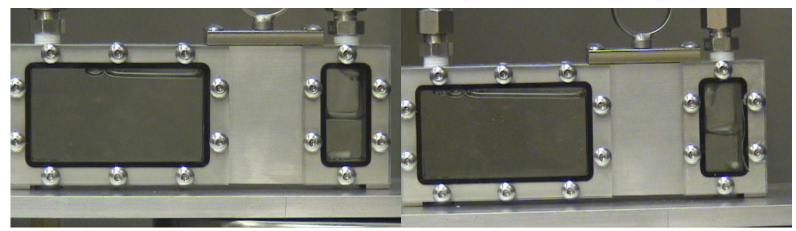
| *Clarity Rankings for All Additives Based on Reservoir and Filter Test Chamber Appearance* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Additive | JP-8 | | P39 | | P41 | | P44 | | P47 | | P50 | | Soup | |
| Run Number | 13 | 31 | 7 | 11 | 16 | 18 | 8 | 10 | 6 | 19 | 9 | 12 | 14 | 20 |
| Dosage | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Reservoir Clarity, 5 hrs | 1 | 1 | 6 | 0 | 1 | 3 | 4 | 4 | 1 | 1 | 1 | 1 | 6 | 0 |
| Resevoir Clarity, 72 hrs | 2 | 3 | 7 | 8 | 4 | 5 | 6 | 6 | 3 | 3 | 2 | 1 | 6 | 4 |
| Resevoir Clarity, 5 Hrs Post-Test | 2 | 2 | 7 | 7 | 4 | 5 | 5 | 5 | 2 | 2 | 1 | 1 | 5 | 3 |
| Free Water Visible @ 5 hrs? | Slight | Slight | No | Slight | Slight | Slight | Light | Light | No | Light | Light | Light | Light | No |
| Free Water Visible @ 72 hrs? | Yes | Yes | Yes | Yes | Light | Light | Yes | Yes | Yes | Yes | Yes | Yes | Light | Light |
| Free Water Visible @ 5 hrs POST-TEST? | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Filter Test Chamber Clarity, 5 hrs | 0 | 0 | 6 | 1 | 0 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 6 | 3 |
| Filter Test Chamber Clarity, 24 Hrs | 0 | 0 | 9 | 9 | 1 | 4 | 9 | 9 | 2 | 3 | 1 | 1 | 9 | 5 |
| Filter Test Chamber Clarity, 72 Hrs | 0 | 1 | 10 | 10 | 6 | 5 | 10 | 10 | 3 | 5 | 1 | 1 | 8* | 5* |
| Clarity Scale: 0 = CLEAR; 4 = Hazy; 6 = Turbid; 8 = Milky; 10 = Foamy | | | | | | * - Soup Test ran 48 hours only | | | | | | | | |

## Reservoir Clarity Visual Ratings



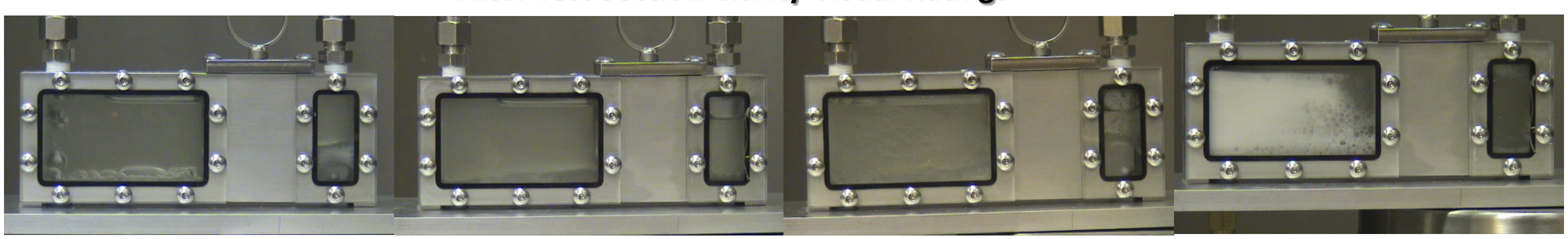
Clarity 0 Clarity 1 Clarity 2 Clarity 4 Clarity 6 Clarity 8

## Filter Test Section Clarity Visual Ratings



Clarity 0 Clarity 2

## Filter Test Section Clarity Visual Ratings



Clarity 4 Clarity 6 Clarity 8 Foamy

**Figure 7 – Clarity Rankings for Fuel Reservoir and Filter Test Chamber**

### 5.2.2 *Additive P39*

The Additive P39 tests were Runs 7 and 11. In Run 7, by 5 hours into the test, the fuel in the reservoir is very turbid. No free water pool is noticeable in the bottom of the reservoir. By 72 hours, the fuel has a very 'milky' appearance although some free water is now pooled at the bottom of the reservoir. 5 hours after the test, the 'milky' appearance remains unchanged. No significant change is noticeable in the amount of free water pooled in the fuel reservoir.

In Run 11, the results were similar to Run 7 except that the fuel in the reservoir was still clear at 5 hours into the test. However, by the end of this run, the fuel was again very 'milky' in appearance. 5 hours after the test, this milky appearance remained although to a slightly lesser degree than at 72 hours.

### 5.2.3 *Additive P41*

The Additive P41 tests were Runs 16 and 18. In Run 16, at 5 hours into the test, the fuel in the reservoir is still very clear with just a slight hint of turbidity. By 72 hours, the fuel is somewhat turbid and a small amount of free water has started to pool. 5 hours after the test, the turbid appearance remains relatively unchanged. A slight increase is noticeable in the amount of free water pooled in the fuel reservoir.

In Run 18, the results were similar to Run 16 except that the fuel appears just slightly more turbid. 5 hours after the test, the turbid appearance remains relatively unchanged. A slight increase is noticeable in the amount of free water pooled in the fuel reservoir.

### 5.2.4 *Additive P44*

The Additive P44 tests were Runs 8 and 10. In both runs, by 5 hours into the test, the fuel in the reservoir is clearly turbid. A slight amount free water pool is noticeable in the bottom of the reservoir. By 72 hours, the fuel has a somewhat milky appearance and free water pooled at the bottom of the reservoir is slightly increased. 5 hours after the test, the turbidity level has decreased to the point where you can actually see through the reservoir. An increase in free water is noticeable in the fuel reservoir.

### 5.2.5 *Additive P47*

The Additive P47 tests were Runs 6 and 19. In both Runs, at 5 hours into the test, the fuel in the reservoir is only slightly turbid. No free water pool is noticeable in the bottom of the reservoir. By 72 hours, the fuel has a turbid appearance although clear enough to almost see through the reservoir. A small amount of free water is now pooled at the bottom of the reservoir. 5 hours after the test, the reservoir has cleared significantly and a substantial amount of free water is pooled in the fuel reservoir.

### 5.2.6 *Additive P50*

The Additive P50 tests were Runs 9 and 12. In both Runs, at 5 hours into the test, the fuel in the reservoir is still very clear. Free water pool is clearly noticeable in the bottom of the reservoir. By 72 hours, the fuel is still very clear with only a hint of turbidity in Run 12 and only slightly turbid in Run 9. A large amount of free water is clearly pooled at the bottom of the reservoir in both Runs. 5 hours after the test, the reservoir in Run 12 has cleared to the appearance at the beginning of the test. In Run 9, the turbidity present at 72 hours is slightly less.

### 5.2.7 *Additive Soup*

The Additive Soup tests were Runs 14 and 20. Contrary to the single-additive Runs, these two Runs show distinctly different results. In Runs 14 a significant amount of turbidity has developed by 5 hours into the test. No free water pool is noticeable in the bottom of the reservoir. By 72 hours, the fuel turbidity is significantly worse and free water has been collecting on the vertical sidewalls of the reservoir. Only a small amount of free water is visible in the bottom of the reservoir. 5 hours after the completion of the test, turbidity is slightly decreased. Free water that has been collecting on the sidewall appears to have larger droplets.

In Run 20, contrary to Run 14, at 5 hours into the test, the fuel remains clear with free water pooling nicely in the bottom of the reservoir. At 72 hours, turbidity is significant with free water pooling in the reservoir. 5 hours after the test, turbidity is decreased, the fuel is clearer and there is more definition to the free water pooled in the reservoir.

## 5.3 Filter Test Chamber Images – APPENDIX

Figures A-8 through A-21 show the appearance of the filter test chamber during testing. In each Figure, the top left image shows the condition of the chamber at the start of the test. The top right image shows the condition of the chamber 5 hours into the test. The bottom left image shows the chamber at 24 hours into the test and the bottom right image shows the chamber at the end of the 72-hour test.

As with the fuel reservoir images, Figure 7 shows a table of subjective assessments of the clarity of the fuel/water in the Filter Test Chamber along with a key relating the numeric clarity ranking to the physical appearance of the reservoir. The author has made an attempt at applying these relative numeric rankings of the clarity in order to attempt to rank the additives in order of effectiveness. *The reader is cautioned that these rankings are very subjective and open to some interpretation. Nonetheless, this ranking seemed to be an appropriate way to cross-compare the test results.*

### 5.3.1 *Baseline JP-8*

The Baseline JP-8 tests were Runs 13 and 31. In both Runs, a slight emulsion can be seen at the 5-hour point and beyond in the right chamber. In the left chamber, the filter/coalescer element has clearly done its job and separated the water and the fuel. Not even slight turbidity is present in this chamber and the fuel and water phases can clearly be seen.

### 5.3.2 *Additive P39*

The Additive P39 tests were Runs 7 and 11. In Run 7, by 5 hours into the test, the fuel in both sides of the filter chamber is very turbid. By 72 hours, the fuel in each side of the chamber has a very 'sudsy' appearance downstream of the filter/coalescer pad (left side) while the right side remains very turbid. Clearly the filter/coalescer element is not functioning to separate and remove the water from the fuel.

In Run 11, the fuel has remained fairly clear at the 5-hour point but by 24 hours the sudsy appearance has returned – although not to the degree of Run 7. Again, in this run clearly the filter/coalescer element is not functioning to separate and remove the water from the fuel.

### 5.3.3 *Additive P41*

The Additive P41 tests were Runs 16 and 18. In both Runs, no emulsion can be seen at the 5-hour or 24-hour points. An emulsion is present by the 72-hour point. At 24 hours, a sudsy emulsion is clearly visible in the left chamber yet there is a clear separation of water and fuel as both phases are clearly visible on the left side of the chamber and the fuel is virtually free of turbidity indicating that the filter/coalescer element is functioning. However, by 72 hours, both sides of the chamber appear turbid and sudsy indicating that the filter/coalescer element has failed. This indicates that the filter/coalescer element is tolerating the additive for a period of time but after long-term exposure, the element fails.

### 5.3.4 *Additive P44*

The Additive P44 tests were Runs 8 and 10. In both Runs, only slight turbidity can be seen at the 5-hour point in the left chamber. However, an emulsion is clearly present in the left chamber by the 24-hour point indicating the filter/coalescer has failed. At 72 hours, a sudsy emulsion is clearly worse in the left chamber appearing turbid and sudsy indicating that the filter/coalescer element has completely failed. This indicates that the filter/coalescer element is tolerating the additive for a short period of time but after some limited exposure, the element fails.

### 5.3.5 *Additive P47*

The Additive P44 tests were Runs 6 and 19. In both Runs, both chambers remain clear until the 72-hour point. At the end of the test, the element is still mostly functioning as there are clearly two separate phases present in the left chamber even though the fuel is slightly turbid. This would indicate that this additive may cause filter/coalescence issues when exposed long term to this additive.

### 5.3.6 *Additive P50*

The Additive P50 tests were Runs 9 and 12. In both Runs, both chambers remain clear through the 72-hour point. There is no apparent turbidity in the fuel even at 72 hours and there is clear separation of fuel and water in the left chamber This indicates that this additive has little or no impact on filter/coalescence performance even when exposed long term to this additive.

### 5.3.7 *Additive Soup*

The Additive Soup tests were Runs 14 and 20. In Run 14, by 5 hours into the test, the fuel in both sides of the filter chamber is very turbid. By 72 hours, the fuel in each side of the chamber has a very turbid appearance yes free water can be observed in the left chamber. However this free water is not clearly distinguishable indicating that the separation may not be very complete. Clearly the filter/coalescer element is only partially functioning to separate and remove the water from the fuel.

In Run 20, the fuel has remained slightly clearer than in Run 14. However, water separation is compromised because the phase separation in the left chamber is not very distinct. As in Run 14, the filter/coalescer element is only partially functioning to separate and remove the water from the fuel.

## 5.4 Summary of Qualitative Results Based On Test Photographs

As would be expected, the results of the qualitative photographic analysis mirror the findings of dissolved water.

The P50 additive appears to have virtually no impact on filter/coalescer performance for at least the duration of this testing. The P47 additive performs almost as well as the P50 additive. The P41 additive exhibits a negative effect on the filter/coalescer element but only after long-term exposure. The P44 additive exhibits a significantly negative impact on filter/coalescer performance beyond just a short period of time where the filter/coalescer functions somewhat normally. The P39 additive and the Additive Soup have a clear and almost immediate negative impact on filter/coalescer performance resulting in element failure shortly after exposure to this additive.

Table 2 is a summary of the relative rankings of each of the additives with regard to Reservoir Clarity (water separation performance) and Filter Test Chamber Clarity (Filter Performance Impact). These rankings were determined based on a mathematical average of the rankings applied and documented in Figure 7. Ranking best performance to worst performance is from top to bottom of Table 2. It is significant to note that in the images as well as the rankings in Table 2, the P50 additive performs better in the JP-8 fuel than the baseline fuel itself with regard to Reservoir Clarity (water separation performance). It is also worthy to note that with the exception of JP-8 and P50 swapping rank positions, the additives ranked the same whether in regard to water separation performance or Filter Performance impact.

**Table 2 – Ranking of Additive Performance for Water Separation and Filter Performance Based on Average Clarity Rankings from Figure 7**

| Ordered Ranking Reservoir Clarity | | | Ordered Ranking Test Section Clarity | |
|---|---|---|---|---|
| Additive | Clarity | | Additive | Clarity |
| P50 | 1.2 | | JP-8 | 0.2 |
| JP-8 | 1.8 | BETTER | P50 | 1.0 |
| P47 | 2.0 | | P47 | 2.5 |
| P41 | 3.7 | | P41 | 2.8 |
| Soup | 4.0 | | Soup | 6.0 |
| P44 | 5.0 | WORSE | P44 | 7.3 |
| P39 | 5.8 | | P39 | 7.5 |

## 6.0 Conclusions and Recommendations

Based on the results of photographic qualitative evidence and dissolved water measurements, Additive P50 performs the best with regard to water separation and filter/coalescer performance impact, being virtually the same as - and in one case, better than - the unadditized fuel. This additive would be the first choice for use if the choice was based solely on water separation and filter/coalescer performance characteristics as it would likely have the least impact on filter/coalescer performance in the field

Additives P47 and P41 perform acceptably with respect to water separation and filter/coalescer performance. Both of these additives initially exhibit no negative impact on filter/coalescer performance but after a short period of exposure to these additives, filter/coalescer performance degrades.

Additives P44, P39 and the Additive Soup exhibit substantial negative impact on both water separation and filter/coalescer performance with P39 ranking the worst as it almost immediately disables the filter/coalescer. P44 and the Soup fair only slightly better.

In conclusion, only additives P50, P47 and P41 exhibit either no or minimal negative impact on water separation and filter/coalescer performance and these additives are the most likely to be able to function in the field with minimal negative impact. However, there is cause for concern that additives P44 and P39 might potentially cause filter/coalescer issues in the field. It is recommended that these two additives be subjected to additional study before being approved for field implementation.

## APPENDIX – PHOTOGRAPHS OF FUEL RESERVOIR AND FILTER CHAMBER TEST SECTION

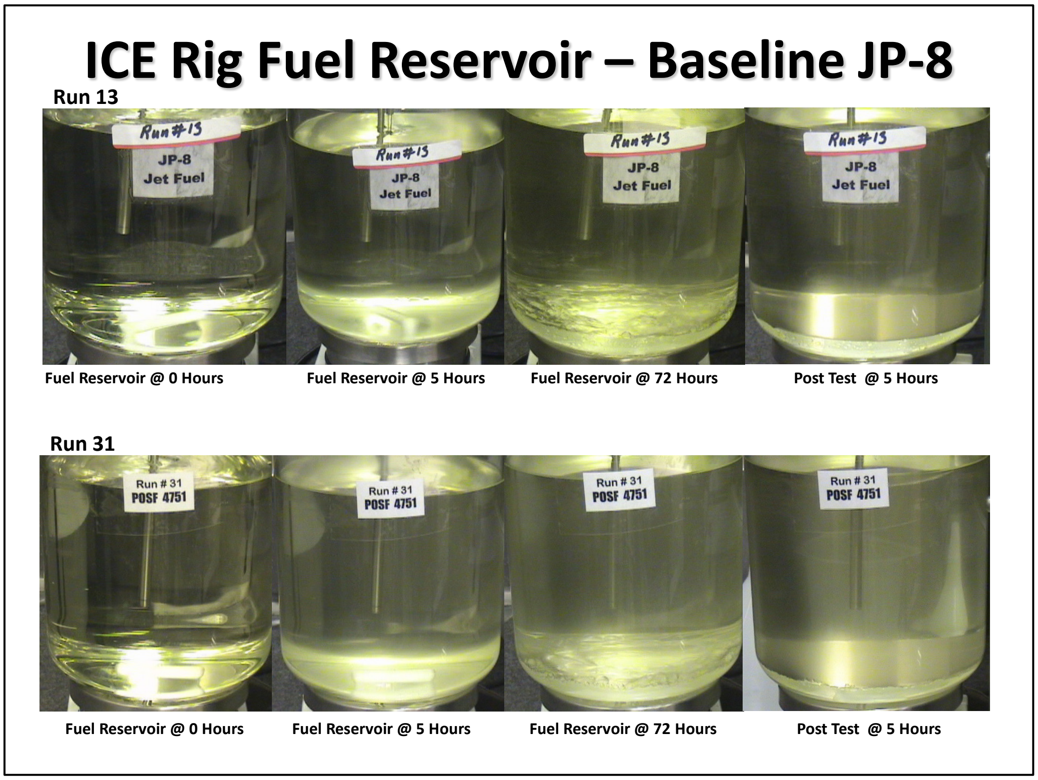



**Figure A- 1 Fuel Reservoir, Baseline JP-8 Fuel at 0, 5 and 72 Hours In Test and 5 Hours Post-Test**

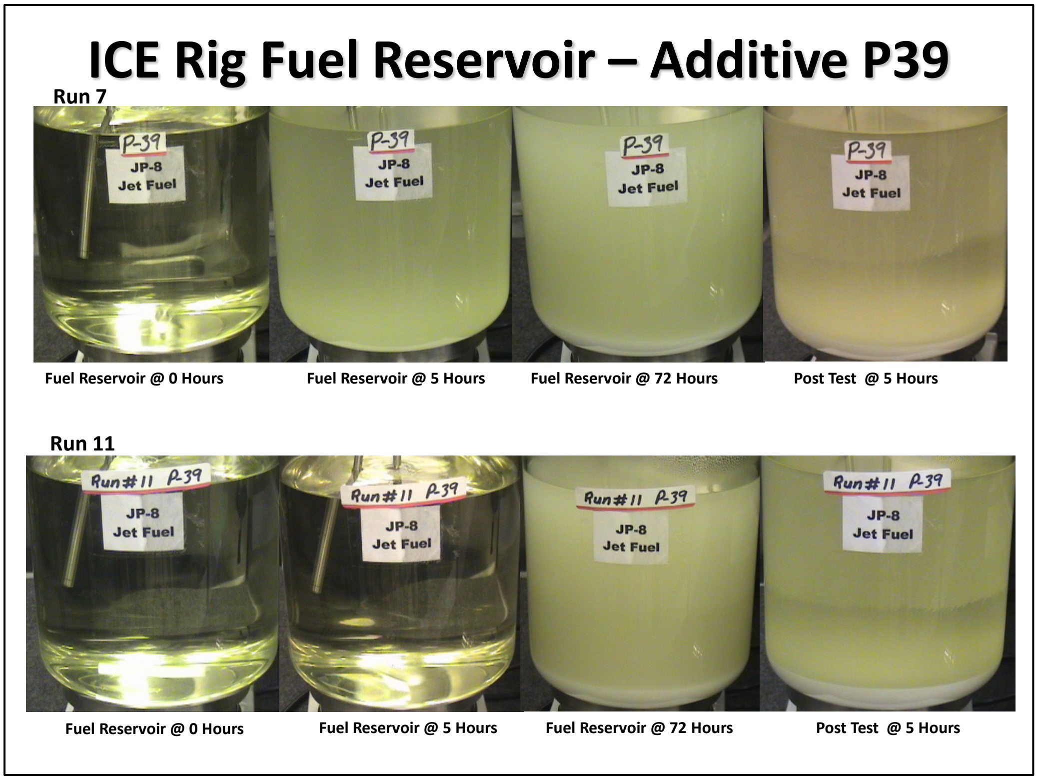



**Figure A- 2 Fuel Reservoir, JP-8 + Additive P39 at 0, 5 and 72 Hours In Test and 5 Hours Post-Test**

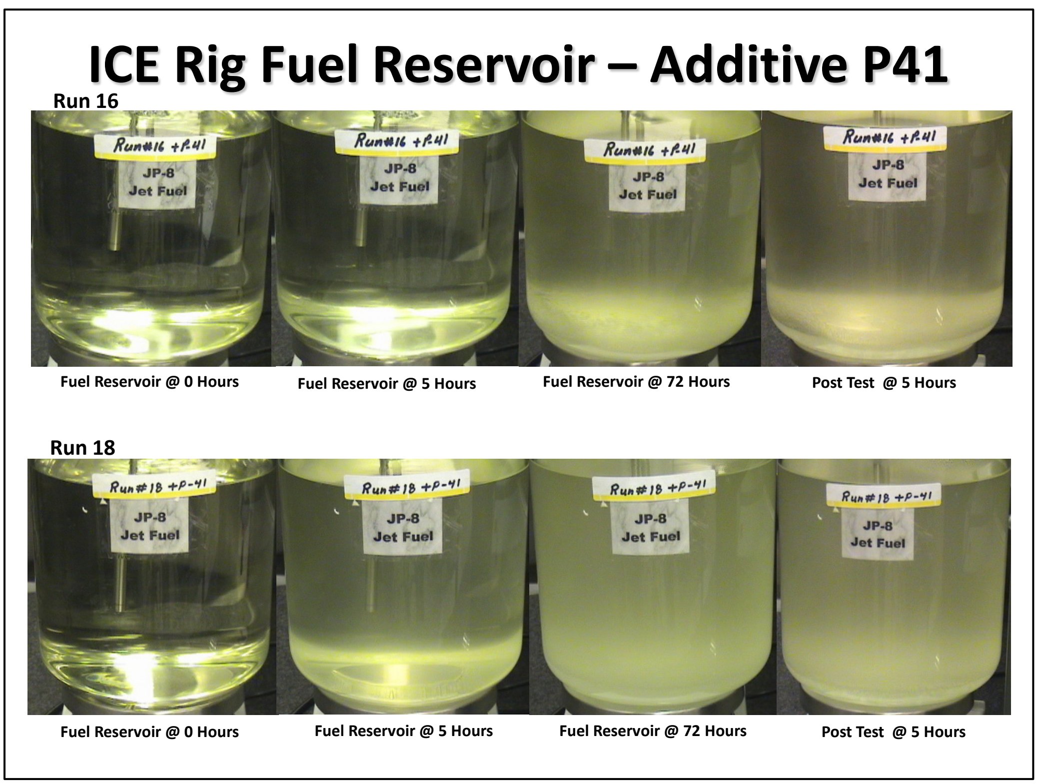



**Figure A- 3 Fuel Reservoir, JP-8 + Additive P41 at 0, 5 and 72 Hours In Test and 5 Hours Post-Test**

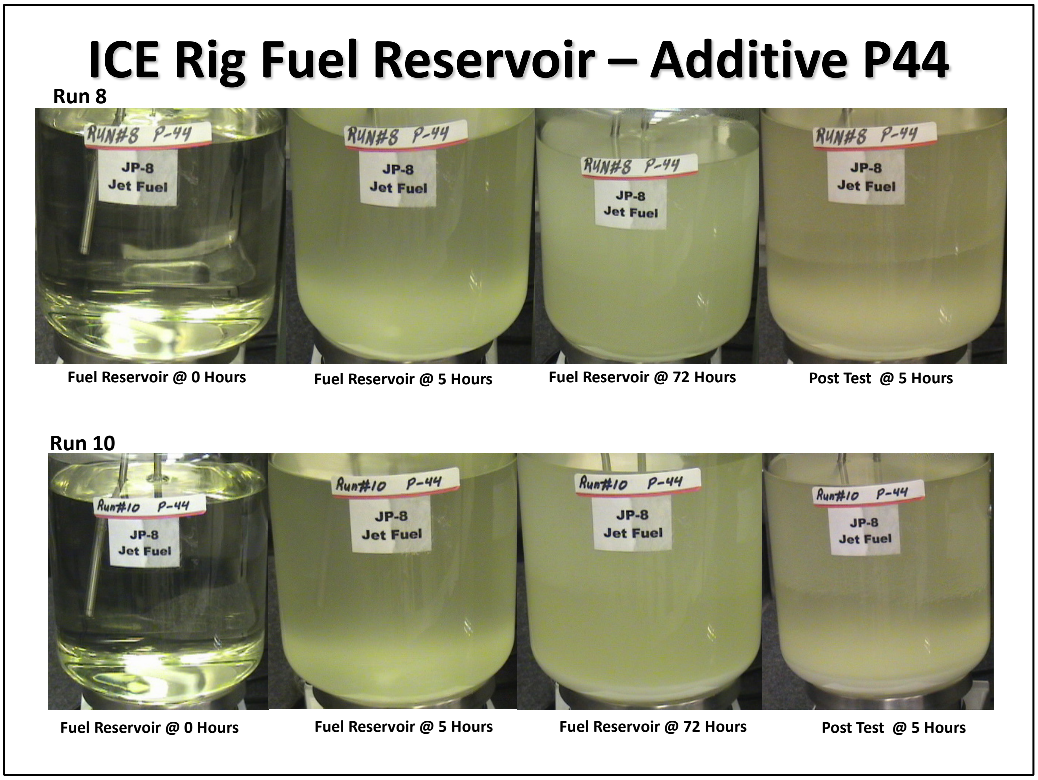



**Figure A- 4 Fuel Reservoir, JP-8 + Additive P44 at 0, 5 and 72 Hours In Test and 5 Hours Post-Test**

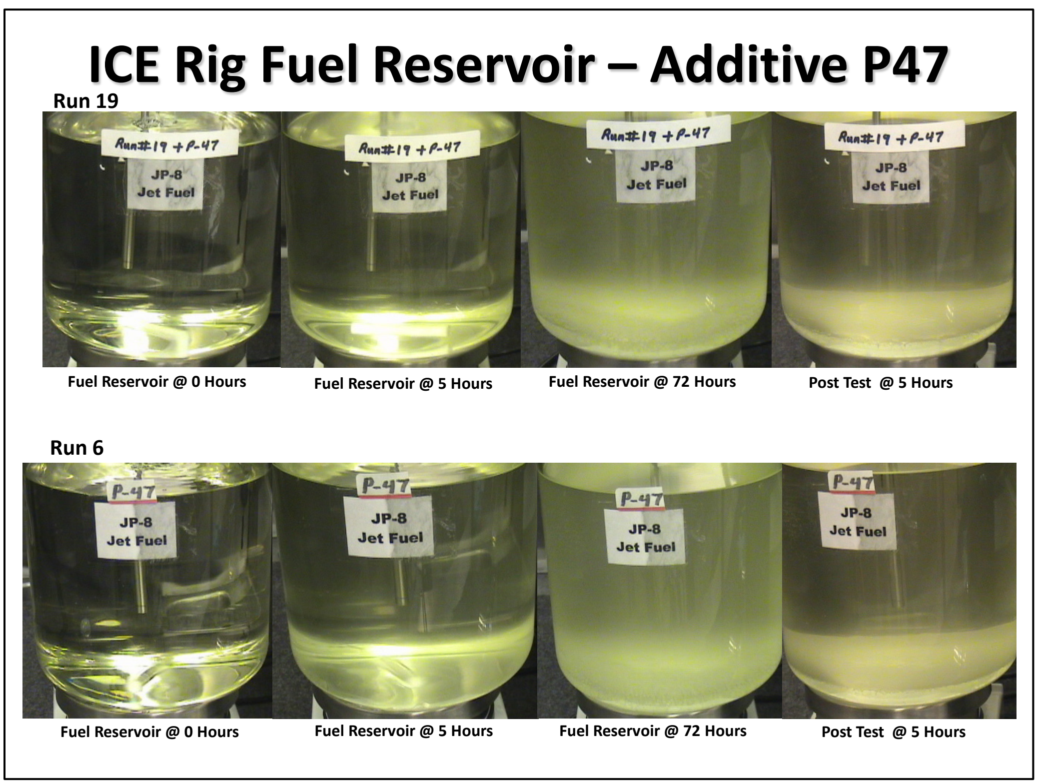



**Figure A- 5 Fuel Reservoir, JP-8 + Additive P47 at 0, 5 and 72 Hours In Test and 5 Hours Post-Test**

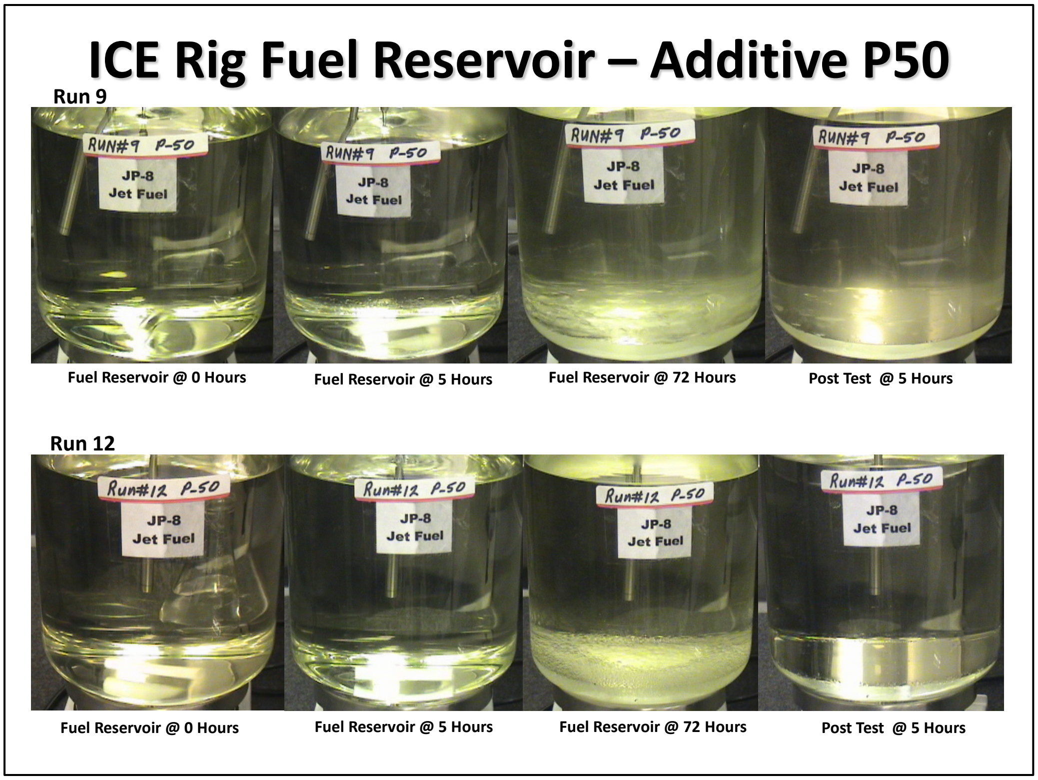



**Figure A- 6 Fuel Reservoir, JP-8 + Additive P50 at 0, 5 and 72 Hours In Test and 5 Hours Post-Test**

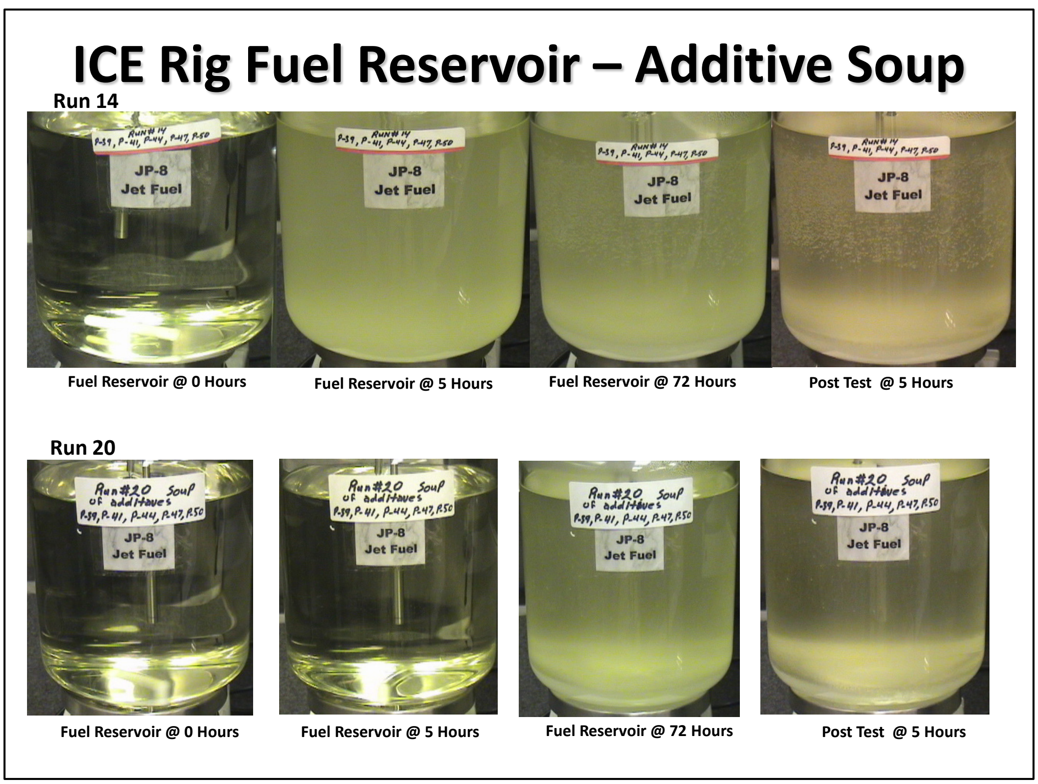



**Figure A- 7 Fuel Reservoir, JP-8 + Additive P50 at 0, 5 and 72 Hours In Test and 5 Hours Post-Test**

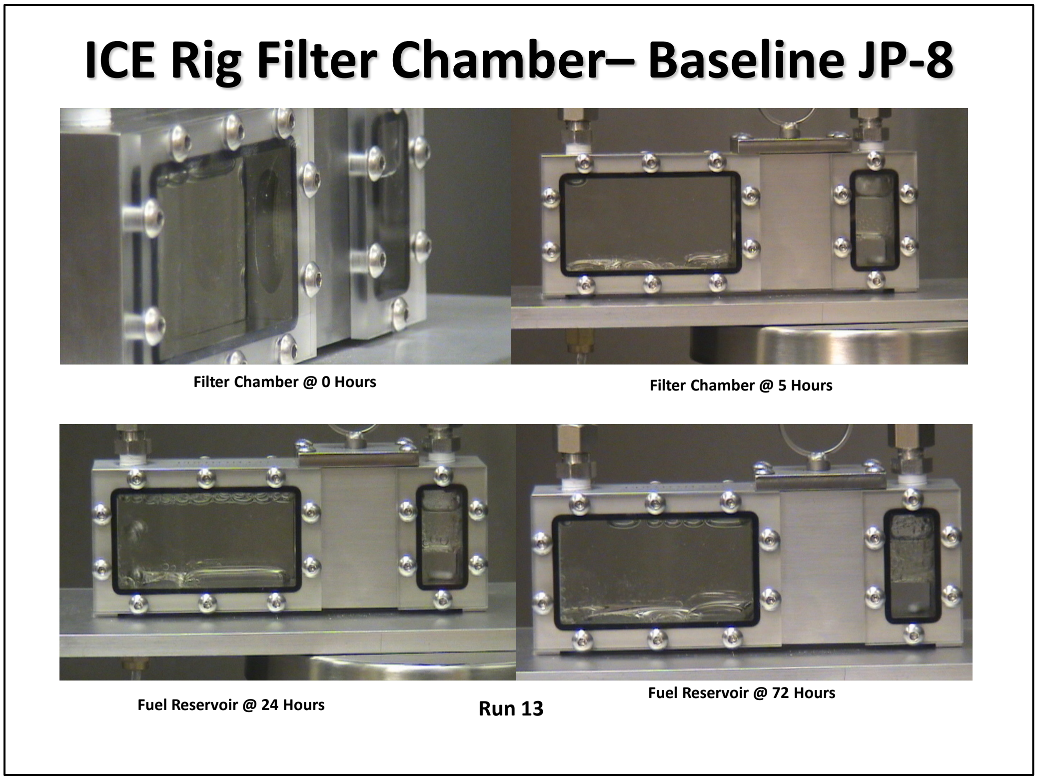



**Figure A- 8 Filter Test Chamber, JP-8 at 0, 5, 24 and 72 Hours In Test – Run 13**

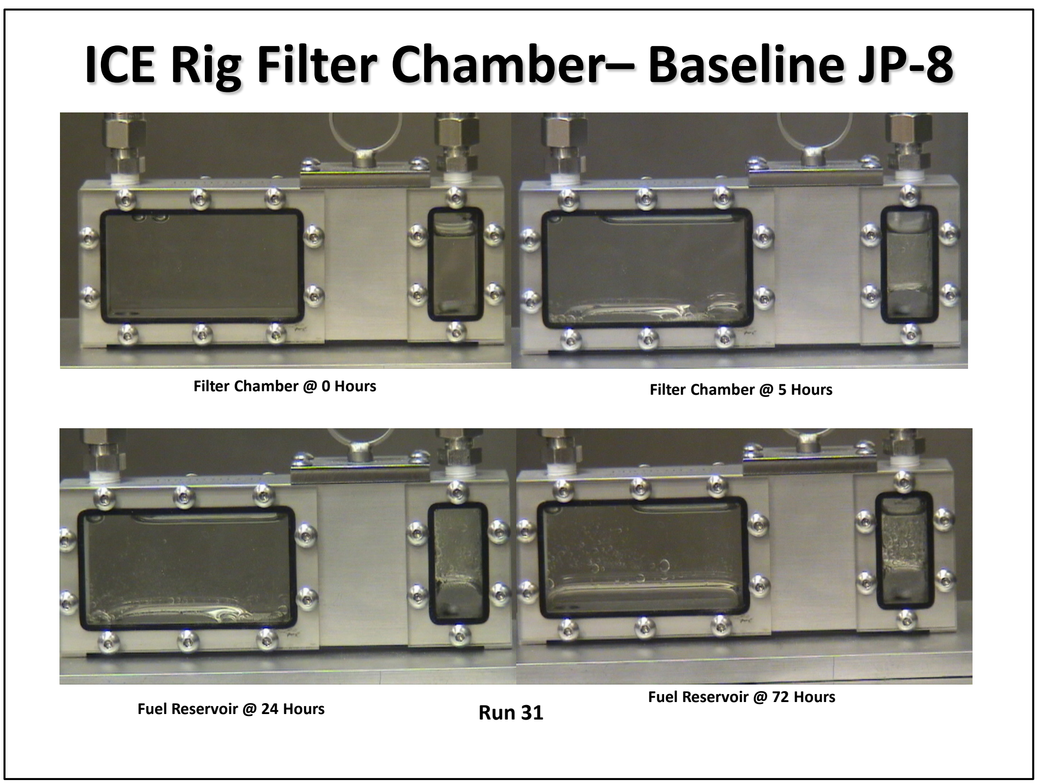



**Figure A- 9 Filter Test Chamber, JP-8 at 0, 5, 24 and 72 Hours In Test – Run 31**

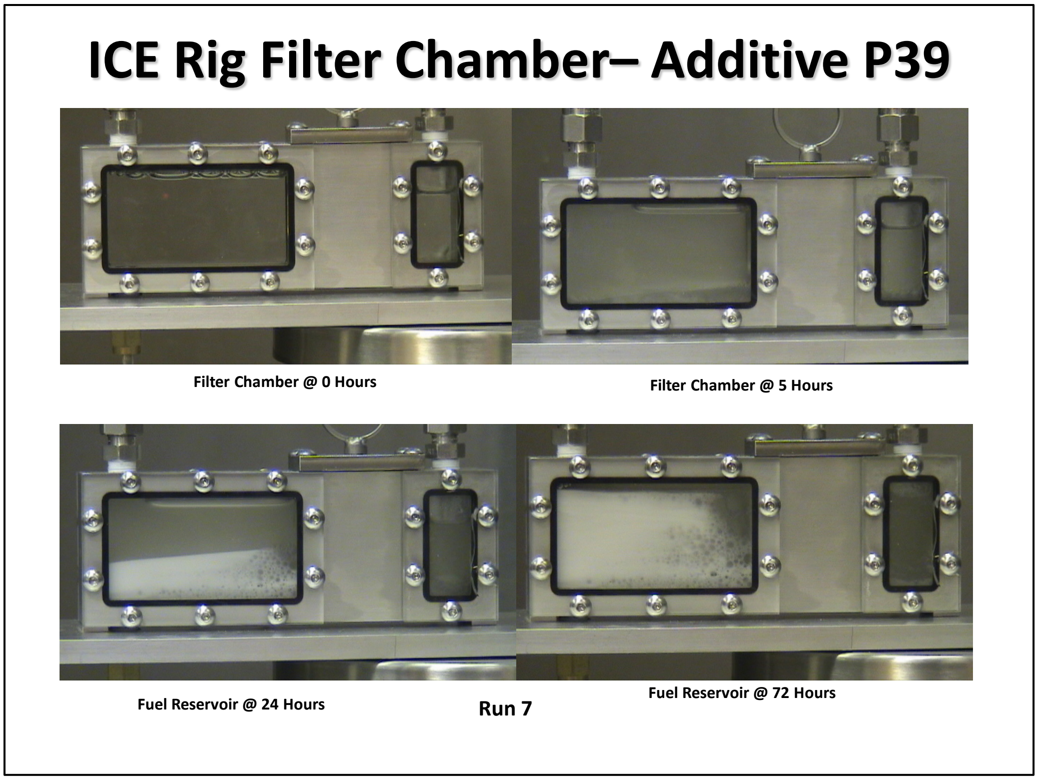



**Figure A- 10 Filter Test Chamber, JP-8+P39 at 0, 5, 24 and 72 Hours In Test – Run 7**

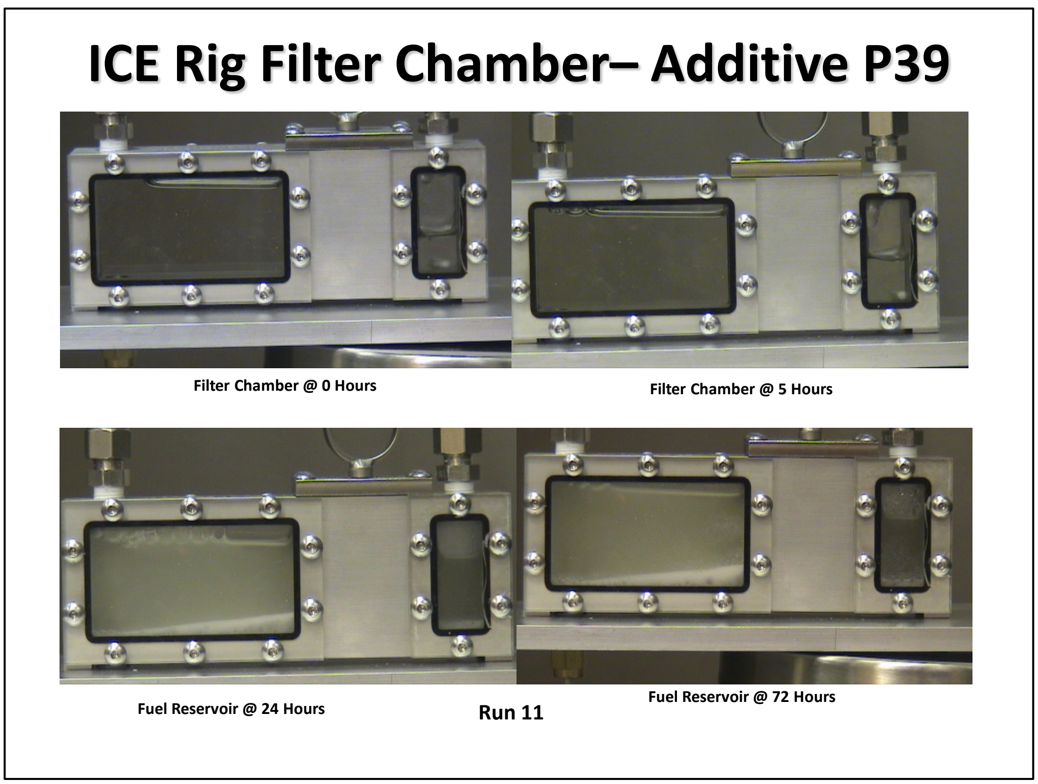



**Figure A- 11 Filter Test Chamber, JP-8+P39 at 0, 5, 24 and 72 Hours In Test – Run 11**

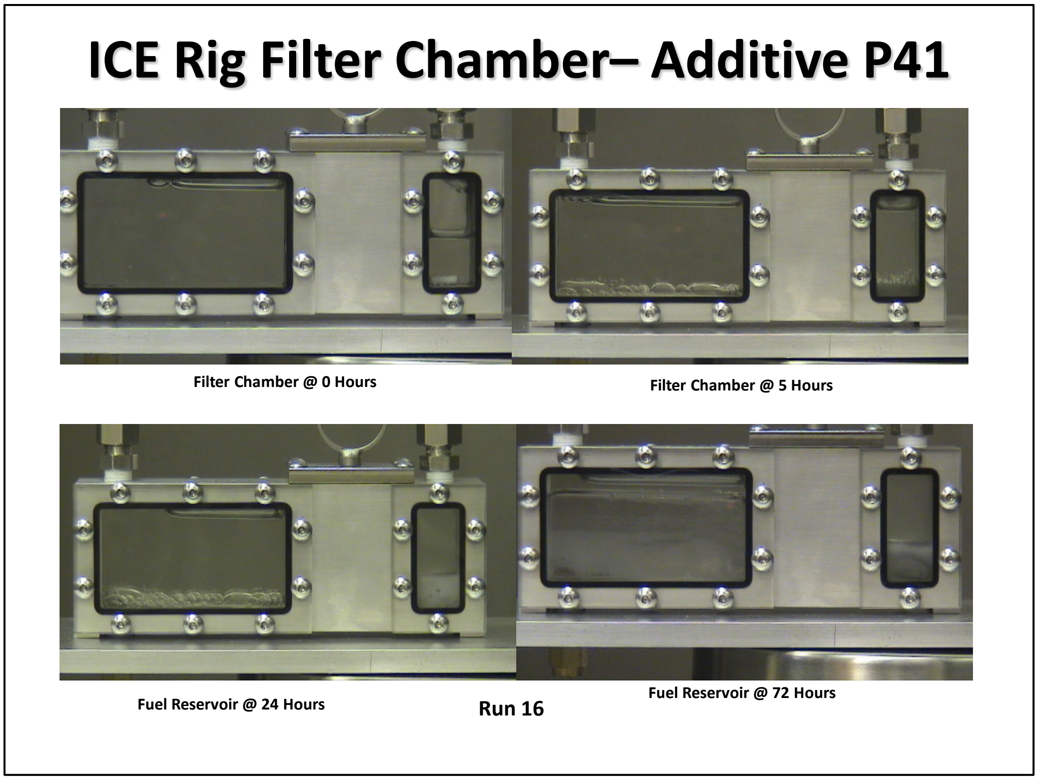



**Figure A- 12 Filter Test Chamber, JP-8+P41 at 0, 5, 24 and 72 Hours In Test – Run 16**

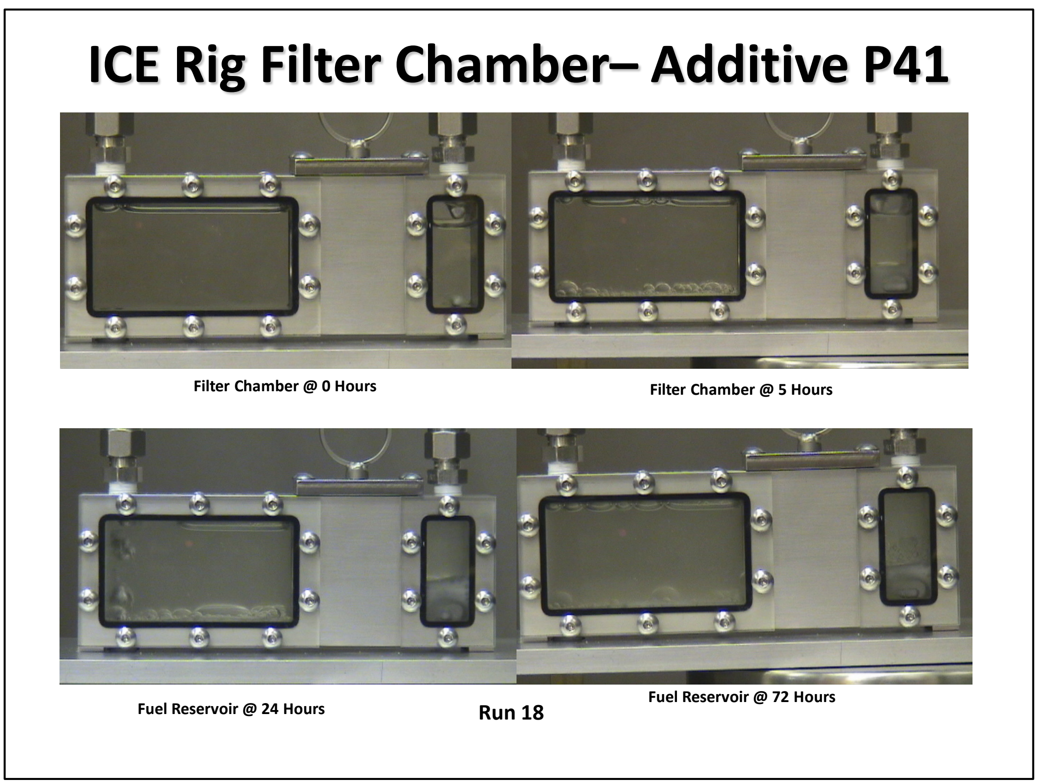



**Figure A- 13 Filter Test Chamber, JP-8+P41 at 0, 5, 24 and 72 Hours In Test – Run 18**

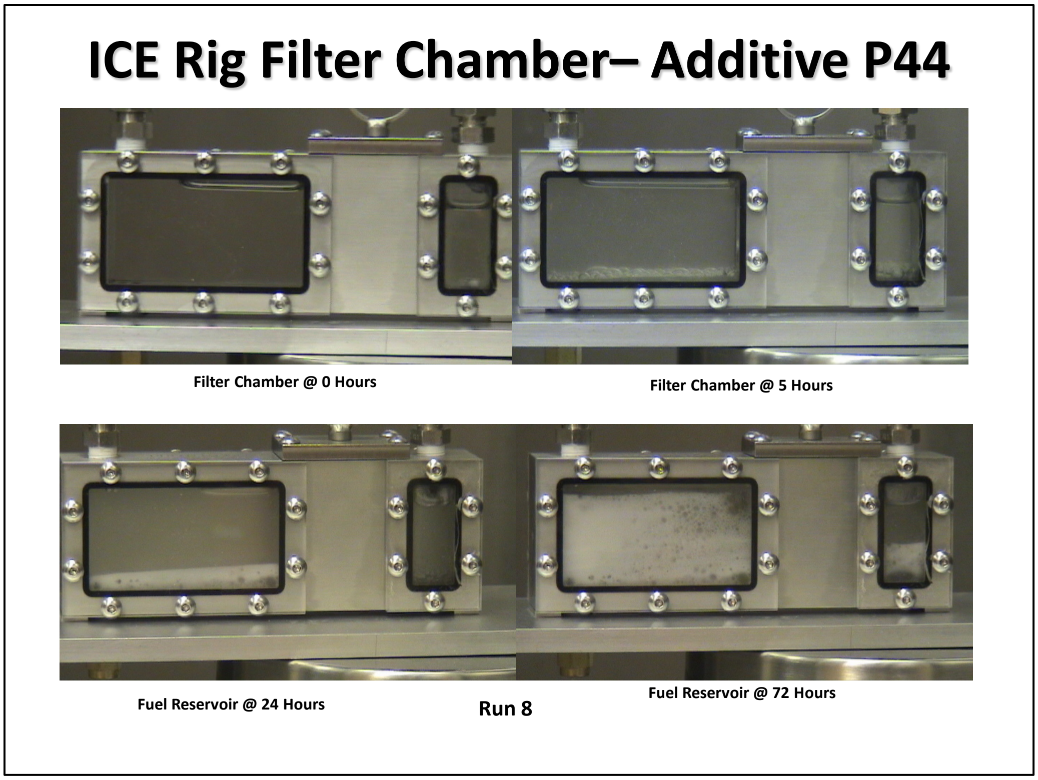



**Figure A- 14 Filter Test Chamber, JP-8+P41 at 0, 5, 24 and 72 Hours In Test – Run 8**

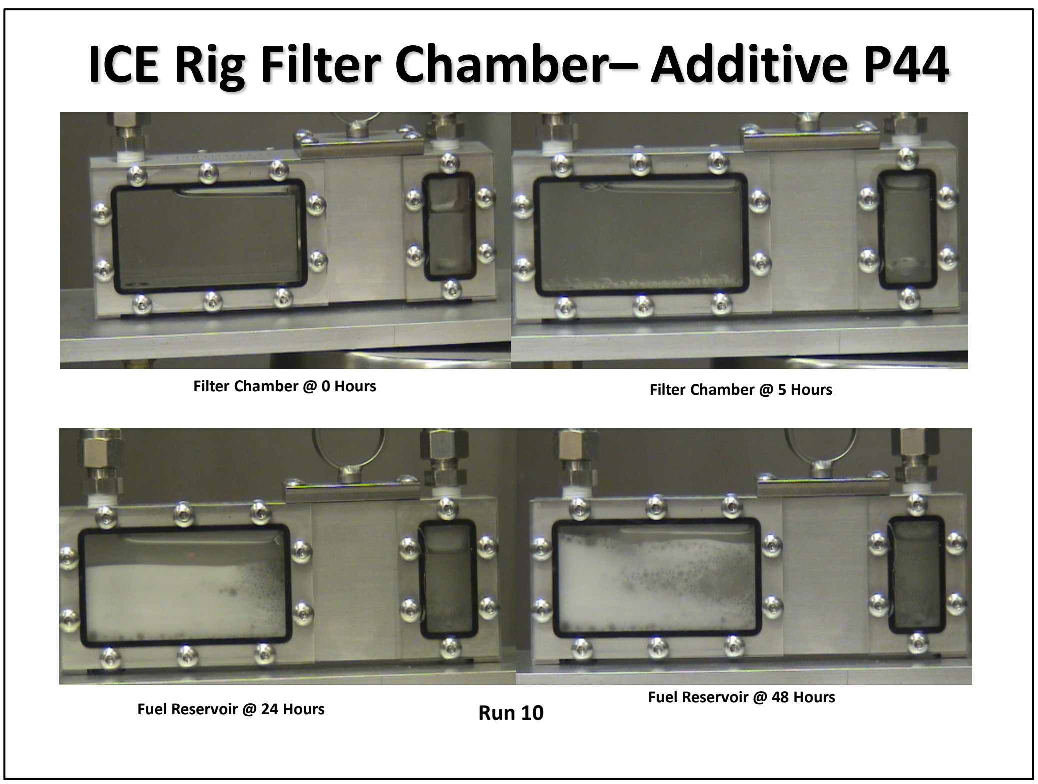



**Figure A- 15 Filter Test Chamber, JP-8+P41 at 0, 5, 24 and 72 Hours In Test – Run 10**

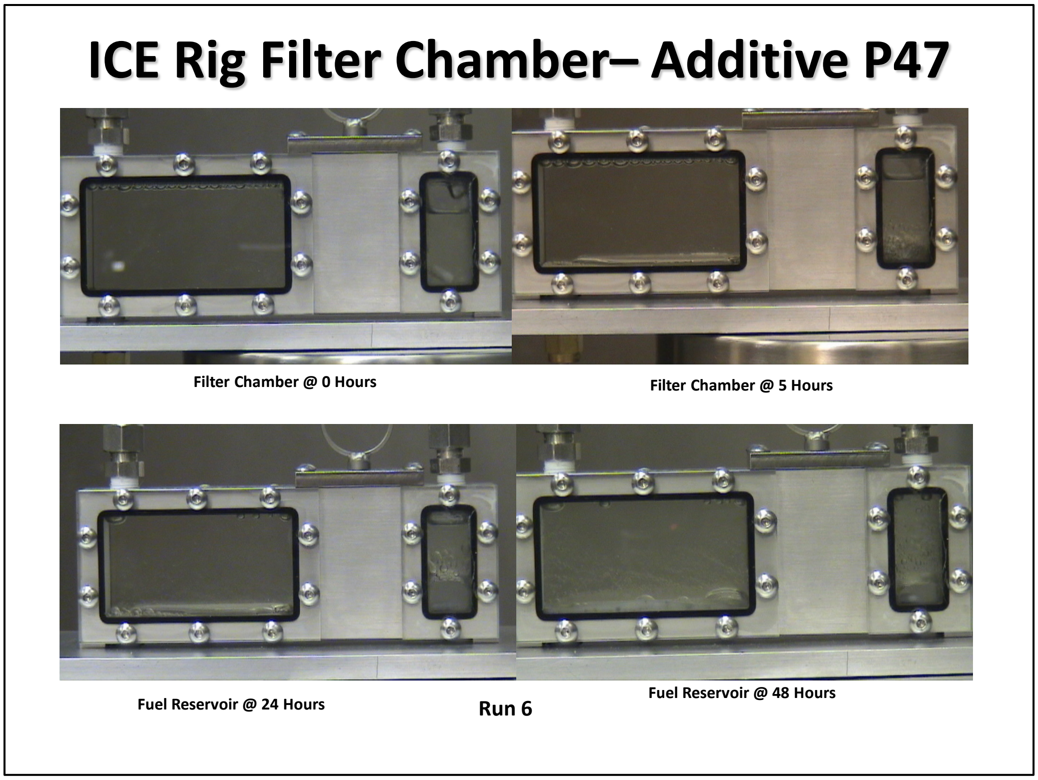



**Figure A- 16 Filter Test Chamber, JP-8+P47 at 0, 5, 24 and 72 Hours In Test – Run 6**

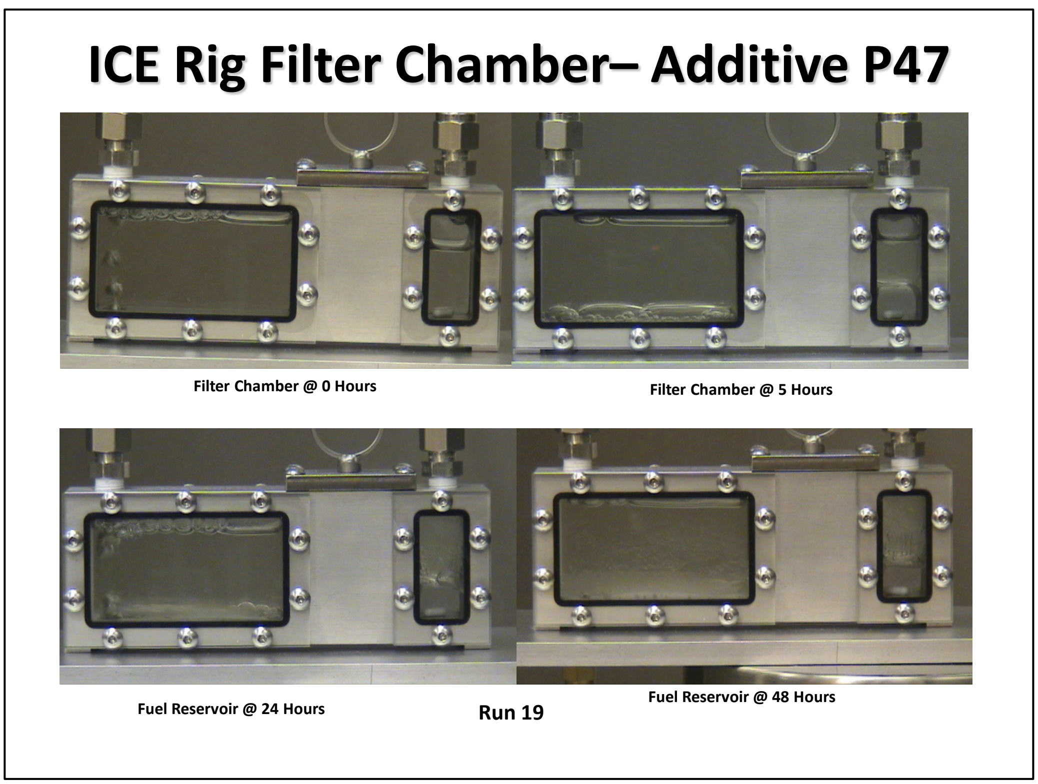



**Figure A- 17 Filter Test Chamber, JP-8+P47 at 0, 5, 24 and 72 Hours In Test – Run 19**

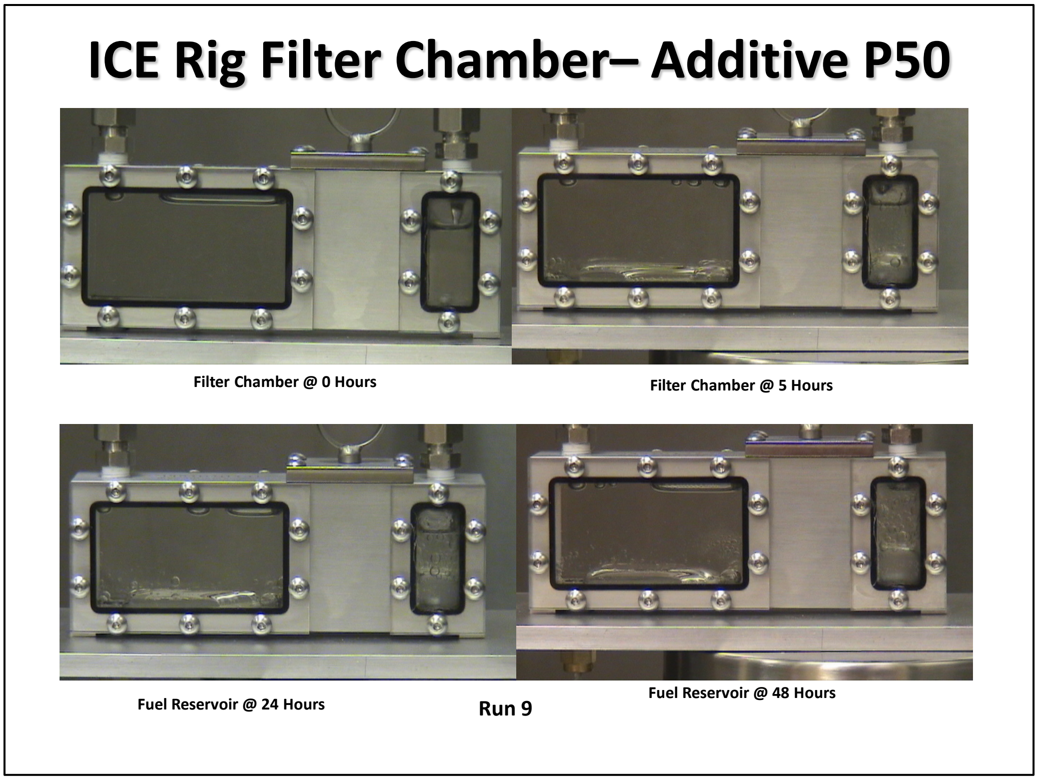



**Figure A- 18 Filter Test Chamber, JP-8+P50 at 0, 5, 24 and 72 Hours In Test – Run 9**

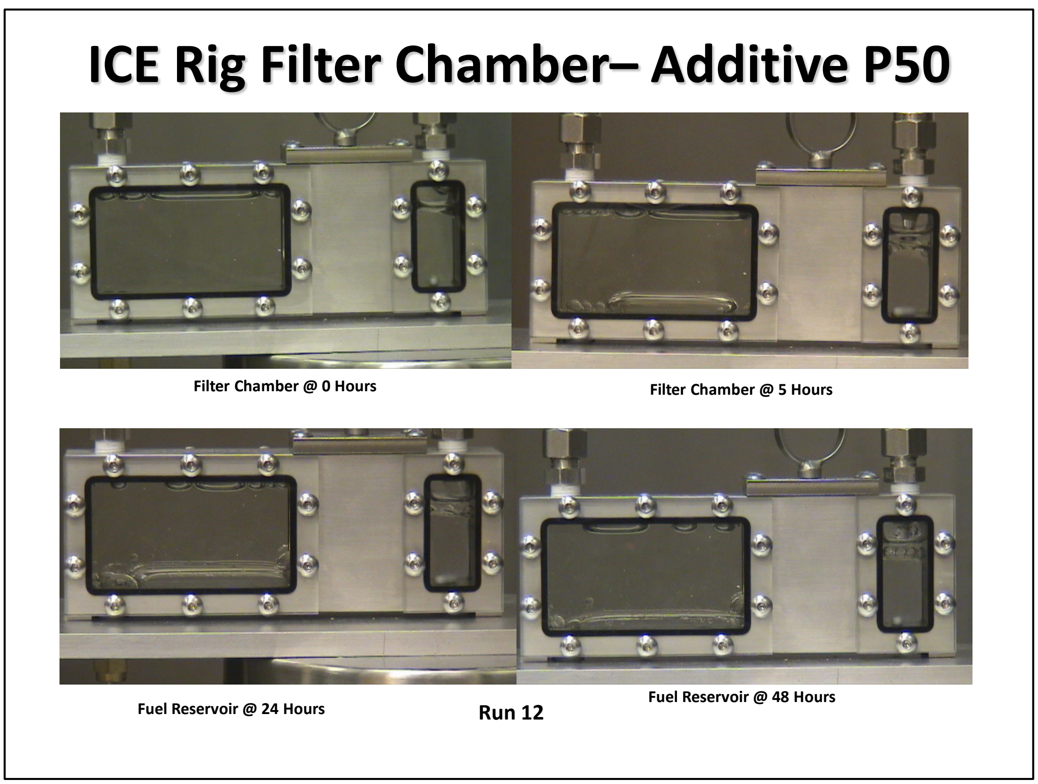



**Figure A- 19 Filter Test Chamber, JP-8+P50 at 0, 5, 24 and 72 Hours In Test – Run 12**

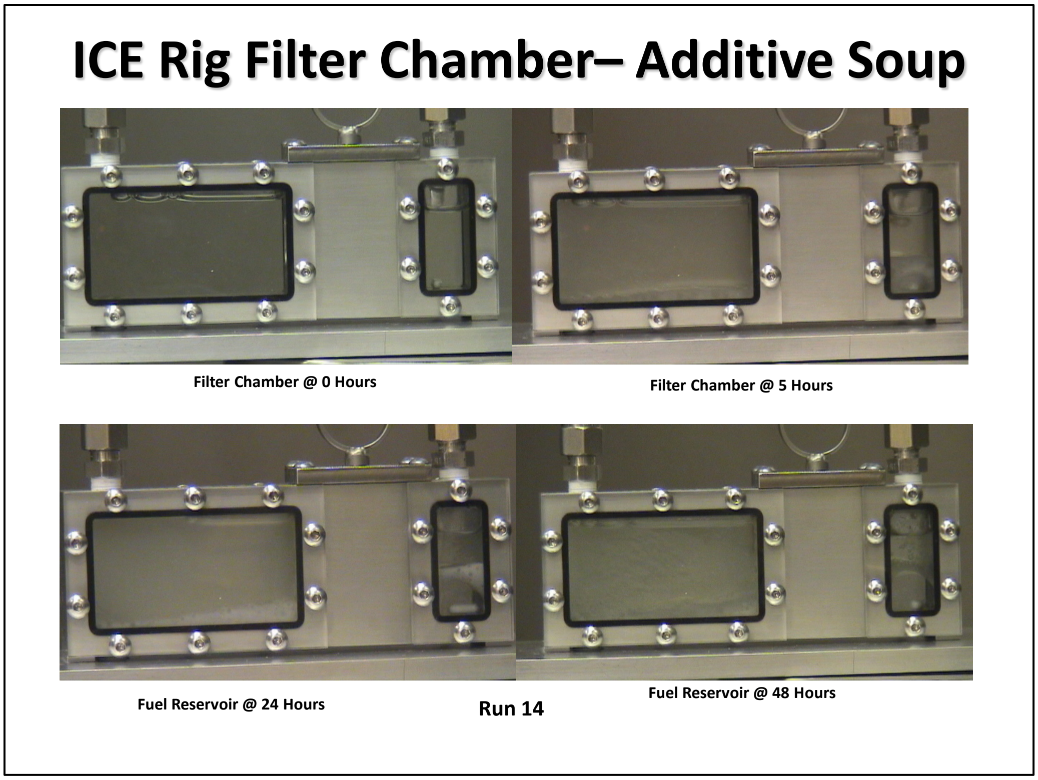



**Figure A- 20 Filter Test Chamber, JP-8+Soup at 0, 5, 24 and 72 Hours In Test – Run 14**

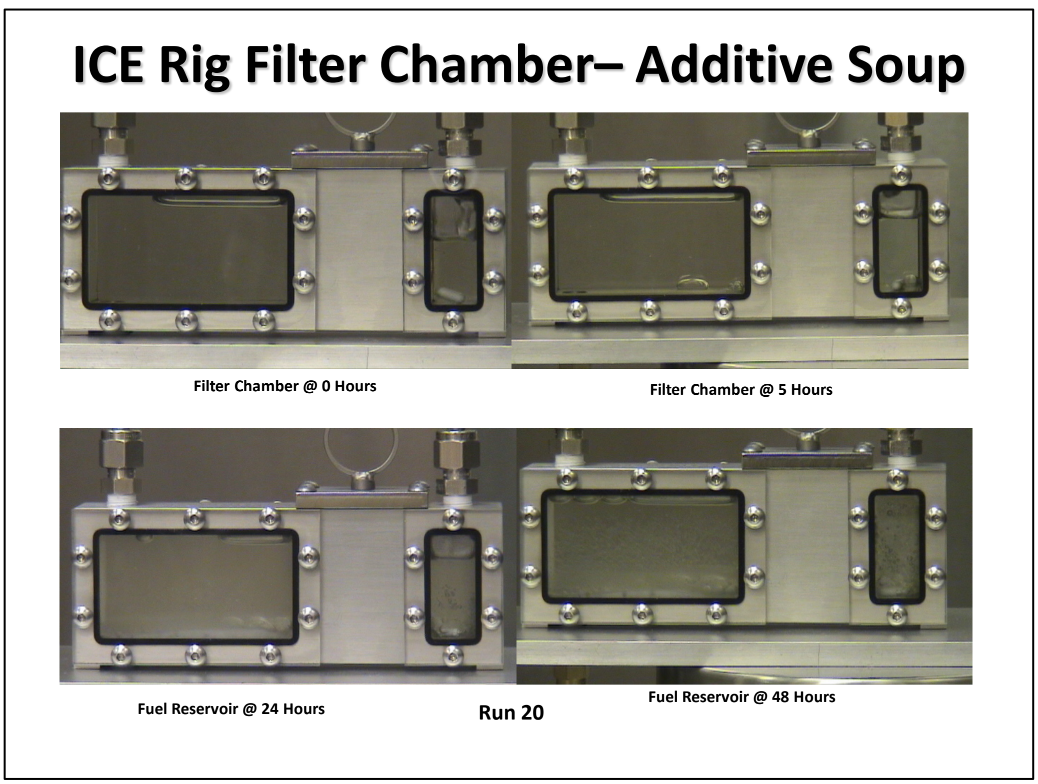



**Figure A- 21 Filter Test Chamber, JP-8+Soup at 0, 5, 24 and 72 Hours In Test – Run 20**